

SUB-SECOND VARIATIONS OF HIGH-ENERGY (> 300 keV) HARD X-RAY EMISSION FROM SOLAR FLARES

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INTRODUCTION

Sub-second variations of hard X-ray emission from solar flares was first observed with a balloon borne detector (Hurley and Duprat 1977). With the launch of SMM, it is now well known that sub-second variations of hard X-ray emission occur quite frequently (Kiplinger et al. 1983, 1984). Such rapid variations give constraints on the modeling of electron energization.

Such rapid variations reported until now, however, have been observed at relatively low energies. Fast mode data obtained by HXRBS has time resolution of ~ 1 ms but has no energy resolution (Orwig et al. 1980). Therefore, rapid fluctuations observed in the fast-mode HXRBS data are dominated by the low-energy (~ 30 keV) hard X-rays. It is of interest to know whether rapid fluctuations are observed in high-energy X-rays. The highest energy band at which sub-second variations have been observed is 223 - 1057 keV (Hurley et al. 1983). In this paper I am going to report sub-second variations observed with HXRBS at energies > 300 keV, and discuss the implications.

OBSERVATIONS

In the normal mode, the time resolution of HXRBS is 0.128 s. Therefore, one can still study sub-second variations of high-energy hard X-rays with normal mode HXRBS data. Because the hard X-ray flux decreases rapidly with increasing energy, in order to observe statistically significant sub-second fluctuations at high energies, one should study flares with high

peak count rates and flat energy spectra. The flare observed at 0118 UT on 1980 June 21 meets both requirements, with the peak count rate being 141,000 counts/s and the spectral index near the X-ray peak being 2.0 (cf. Bai and Dennis 1985).

Figure 1 shows time profiles of four energy bands (28 - 55, 55 - 125, 125 - 259, 259 - 484 keV), with integration time 0.128 s. Figure 2 shows a time profile of 290 - 484 keV X-rays. The vertical bars in these figures indicate one-sigma error bars. We can see statistically significant rapid variations at several places in Figure 2, with time scales as short as 0.1 or 0.2 s.

INTERPRETATION

The energy loss rate of electrons due to Coulomb collisions is given (for $E > 150$ keV) by

$$(dE/dt) = -3.8 \times 10^{-10} n \text{ keV/s}, \quad (1)$$

where n is the ambient electron density in cm^{-3} . The energy loss time for 300 keV electrons is then given by

$$E (dE/dt)^{-1} = 79 \times (10^{12}/n) \text{ s}. \quad (2)$$

Therefore, the electrons responsible for the sub-second decreases must have interacted in a medium with density $> 10^{12} \text{ cm}^{-3}$, i.e., below the transition region. Rapid rise of high-energy X-rays indicates rapid increase of the number of high-energy electrons in the interaction region.

In interpreting the sub-second variations shown in Figure 2, I can think of the following two alternatives:

(1) High-energy electrons were accelerated with small pitch angles, and they immediately penetrate below the transition region to radiate there while losing energy. The rapid variations of the high-energy hard X-ray flux are due to rapid change in production rate of high-energy electrons.

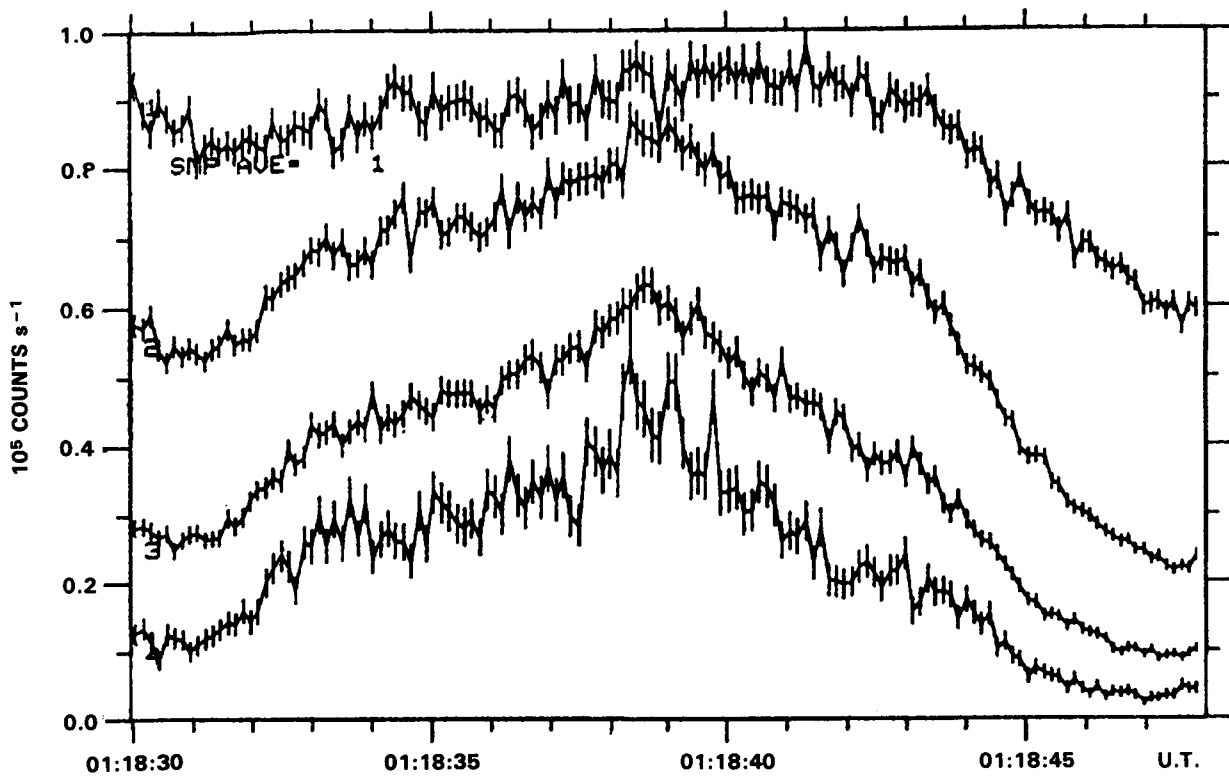


Figure 1. High resolution hard X-ray time profiles of the 1980 June 21 flare. From top to bottom, the 4 (four) curves are time profiles of X-rays in the 4 energy bands (28 – 55, 55 – 125, 125 – 259, 259 – 484 keV). Integration time is 0.128 s, and one-sigma error bars are shown.

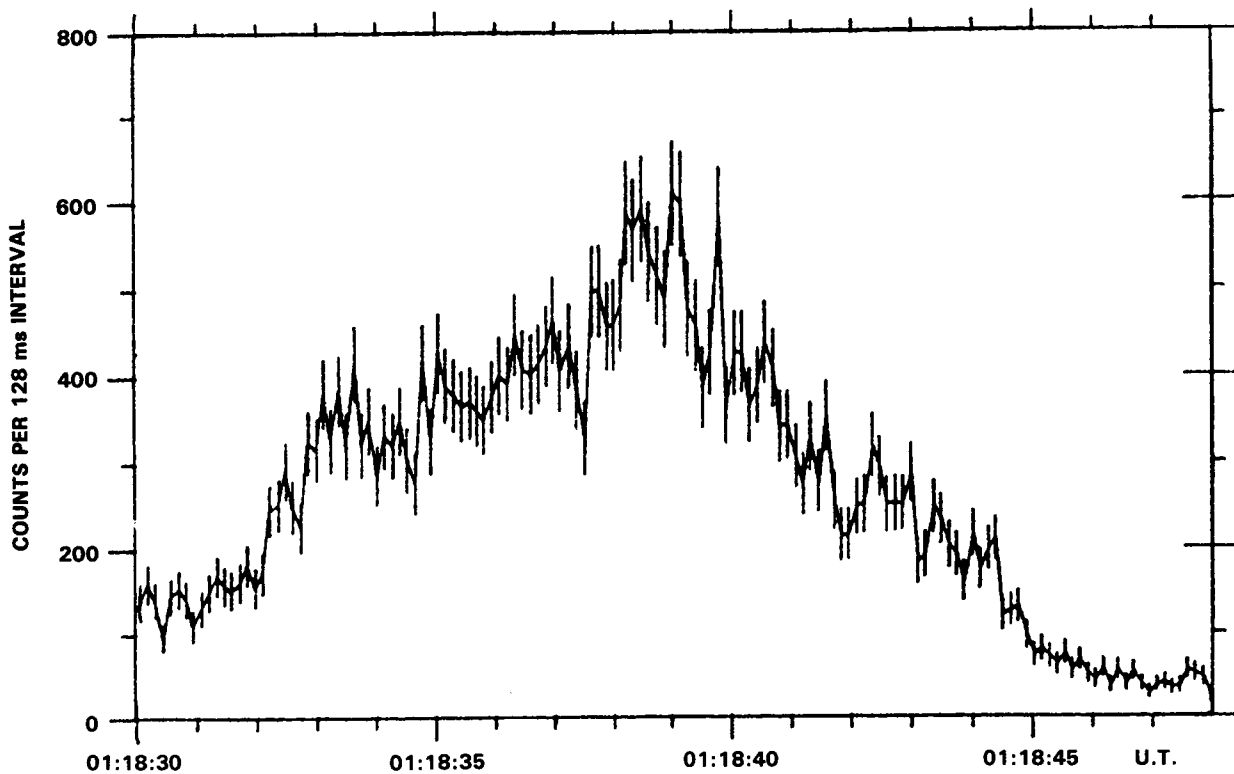


Figure 2. Same as Fig. 1, for energy band 290 – 484 keV. (Figures, courtesy of Brian Dennis)

(2) High-energy electrons are accelerated with large pitch angles, and they are initially trapped in the magnetic loop with density $< 10^{11} \text{ cm}^{-3}$. Once in a while some instability develops which rapidly scatters energetic electrons into the loss cone. The rapid variations of the high-energy hard X-rays are due to rapid scattering of high-energy electrons.

For the following reason I think the first alternative is a more likely scenario. One can estimate the efficiency of microwave emission of solar flares by comparing the microwave peak density to the hard X-ray peak flux. For this purpose, Bai (1986) defined microwave-richness index (MRI) as follows:

$$\text{MRI} = \frac{\text{peak flux density of 9 GHz microwaves (sfu)}}{\text{HXRBS peak count rate (counts/s)}} \times 10. \quad (3)$$

When defined as such, the median value of MRI for flares observed in 1980 through 1981 is about unity. Relatively speaking, flares with $\text{MRI} > 1$ are more efficient in producing 9 GHz microwaves than flares with $\text{MRI} < 1$. For the 1980 June 21 flare, the MRI is 0.097 (Bai and Dennis 1985). This means that this flare was ten times less efficient in microwave emission than the average flare. This flare had flat hard X-ray spectrum with spectral index 2.0. Therefore, this flare produced large numbers of high-energy electrons, as evidenced from the large count rate of high-energy X-rays shown in Figures 1 and 2. High-energy electrons are very efficient emitters of microwaves; nevertheless this flare has a small MRI. The most plausible way of suppressing microwave emission is to accelerate high-energy electrons with small pitch angles and inject them below the transition region.

CONCLUSION

We have seen sub-second variations of high-energy ($> 300 \text{ keV}$) X-rays in the 1980 June 21 flare. Such rapid variations are interpreted to be due to rapid acceleration of high-energy electrons with small pitch angles. This

flare occurred at the Western limb (N19 W90), and continuum radiation above 10 MeV was observed from this flare (Rieger et al. 1983). This continuum is mostly due to bremsstrahlung by highly relativistic electrons (Chupp 1984). The decay time of this continuum is several seconds, and from this one can deduce that these highly relativistic electrons interacted below the transition region, similarly to > 300 keV electrons.

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